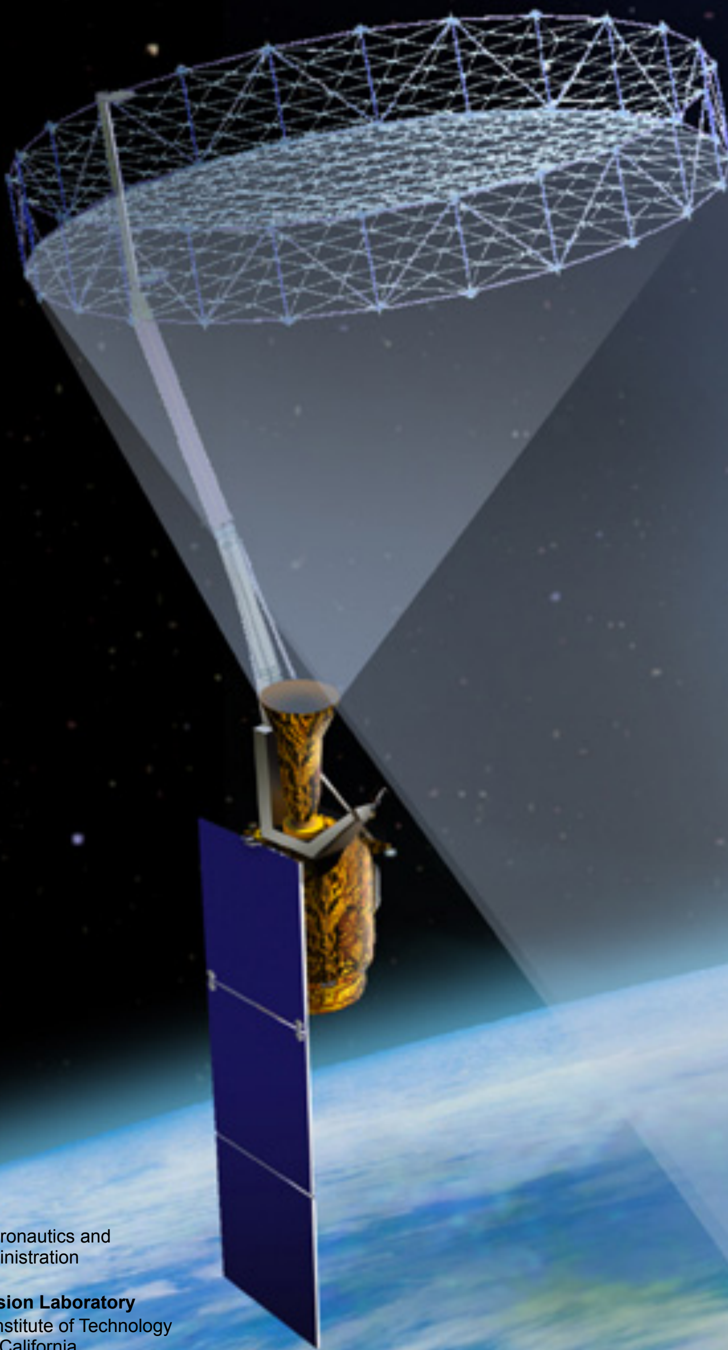
Soil Moisture Active and Passive (SMAP) Mission

Dara Entekhabi[1], E. Njoku[2], P. O'Neill[3], M. Spencer[2], Kent Kellogg[2], J. Entin[4], J. C. Shi[5], T. Jackson[6]

[[1]MIT; [2]CalTech/JPL; [3]NASA/GSFC; [4]NASA HQ; [5]UCSB, [6]USDA]

March 25, 2009
PIERS 2009 Beijing



National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Project/Mission Overview—Mission Context

US National Research Council Report: "Earth Science and Applications from Space: National Imperatives for the next Decade and Beyond"

SMAP is one of four missions recommended by the NRC Earth Science Decadal Survey for launch in the 2010–2013 time frame

Tier 1: 2010–2013 Launch
Soil Moisture Active Passive (SMAP)
ICESAT II
DESDynI
CLARREO
Tier 2: 2013–2016 Launch
SWOT
HYSPIRI
ASCENDS
GEO-CAFE
ACE
Tier 3: 2016–2020 Launch
LIST
PATH
GRACE-II
SCLP
GACM
3D-WINDS

- On Feb 2, 2008, NASA announced that SMAP would be one of two new start missions initiated in FY08
- SMAP is a directed NASA mission with significant heritage from Hydros
- Hydros risk-reduction performed during Phase A (instrument, spacecraft dynamics, science, ground system) Cancelled 2005 due to NASA budgetary constraints

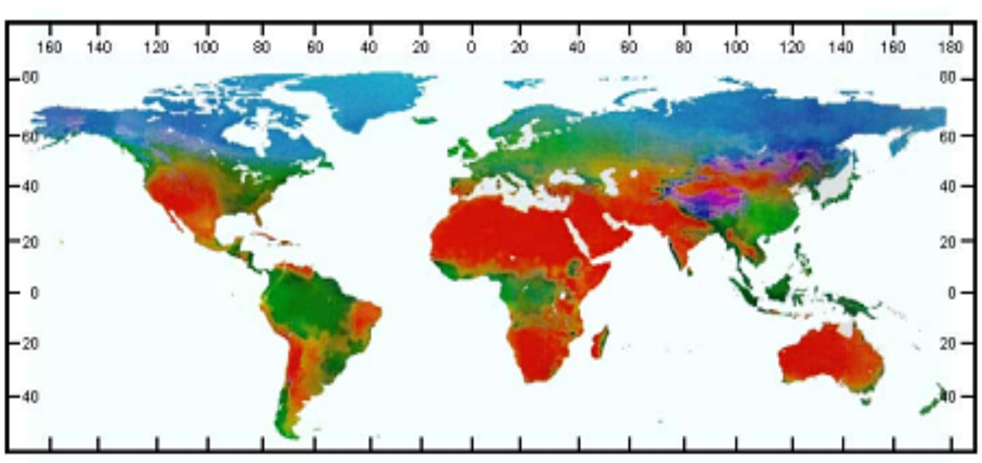
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Mission Science Objective

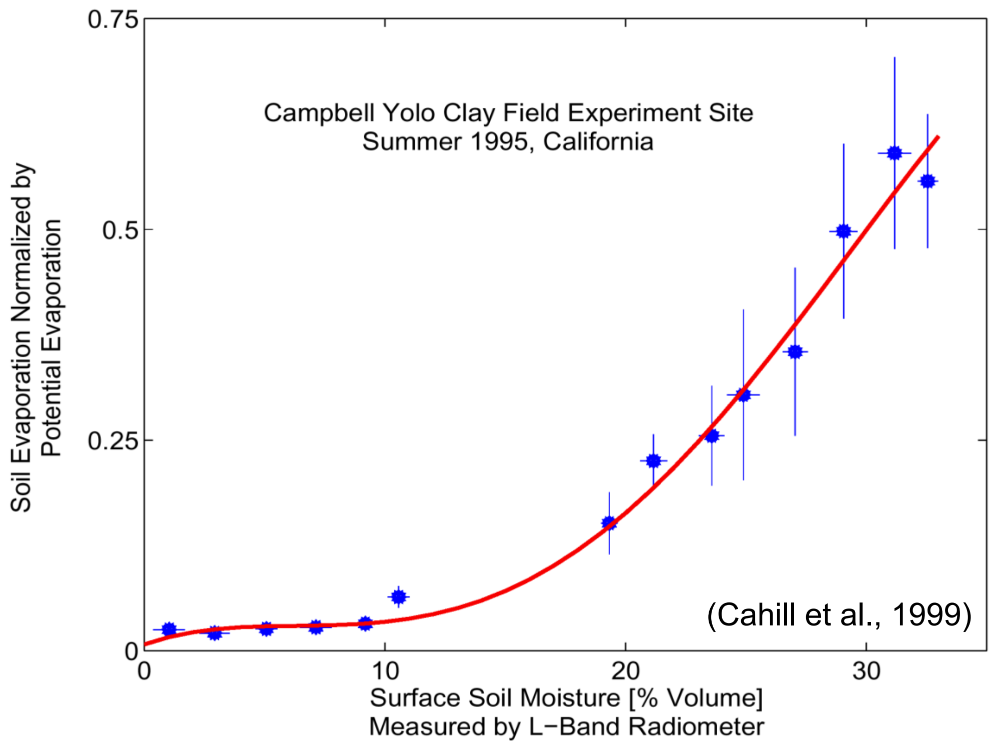
Global mapping of Soil Moisture and Freeze/Thaw state to:

- Understand processes that *link* the terrestrial water, energy & carbon cycles
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Enhance weather and climate forecast skill
- Develop improved flood prediction and drought monitoring capability



Primary Controls on Land Evaporation and Biosphere Primary Productivity

Key Determinants of Land Evaporation



Latent heat flux (evaporation) *links* the water, energy, and carbon cycles at the surface.

Lack of knowledge of soil moisture control on evaporation causes uncertainty in land surface and atmospheric models.

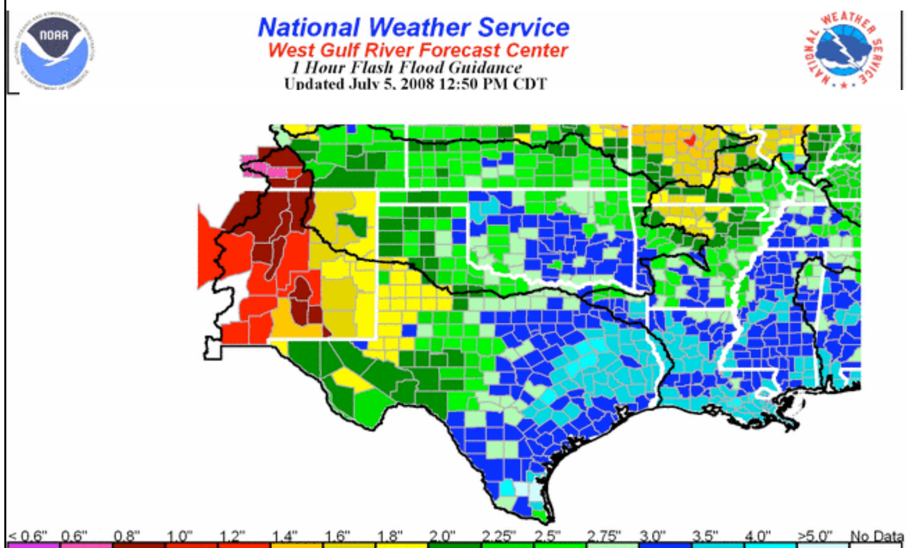
SMAP surface soil moisture observations would reduce uncertainty in this key relationship globally.

National Aeronautics and Space Administration

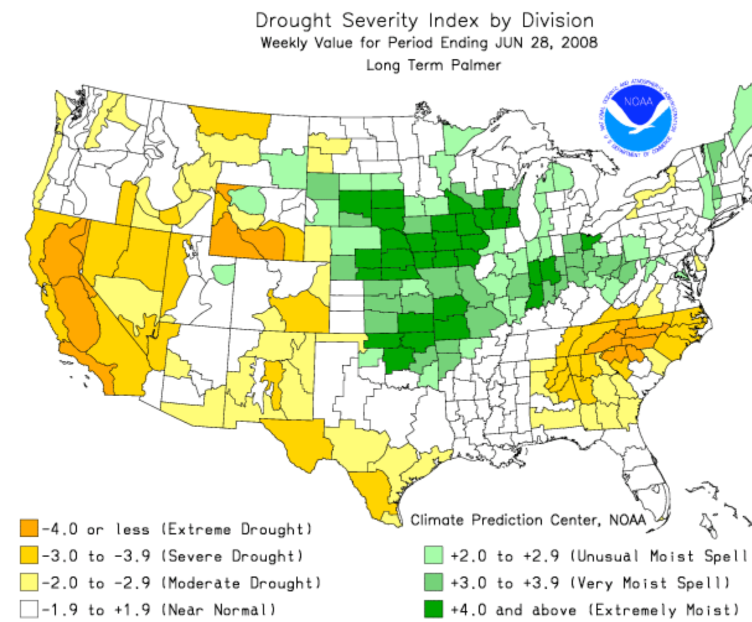
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Flood Prediction and Drought Monitoring

Current NWS Operational
Flash Flood Guidance (FFG)



Current Operational Drought Indices by NOAA
(NIDIS - National Integrated Drought Information System)



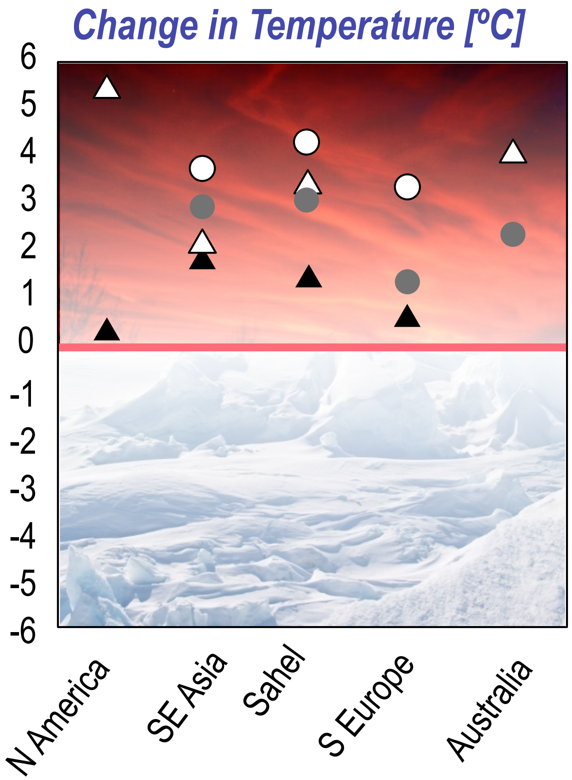
Current: Empirical Soil Moisture Indices Based on Rainfall and Air Temperature
(By Counties >40 km and Climate Divisions >55 km)

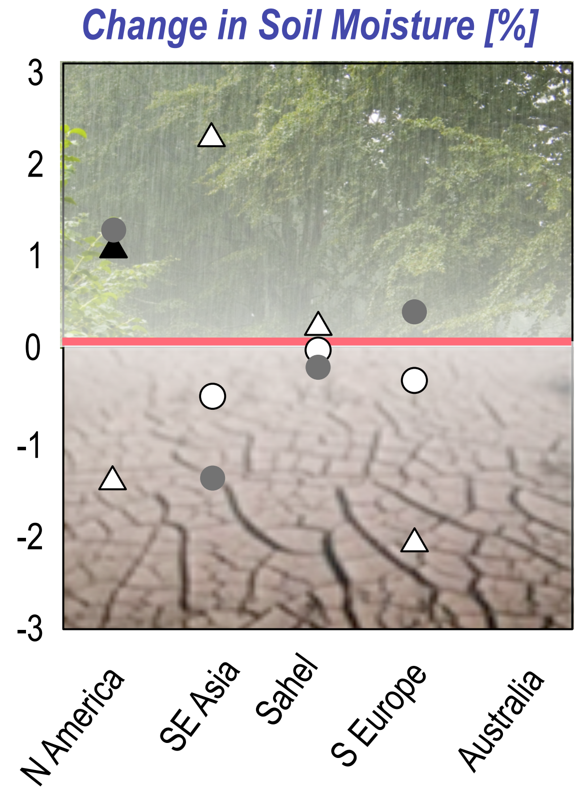
Future: SMAP Soil Moisture Observations at 10 km

Climate Change and Water Resources Impacts

Intergovernmental Panel on Climate Change (IPCC) AR4 climate model projections by region:

Models *agree* on basic temperature response





Models *disagree* on whether there would be MORE or LESS water compared to today

Li et al., (2007): Evaluation of IPCC AR4 soil moisture simulations for the second half of the twentieth century, *Journal of Geophysical Research*, 112.

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Science Requirements

DS Objective	Application	Science Requirement
Weather Forecast	Initialization of Numerical Weather Prediction (NWP)	Hydrometeorology
Climate Prediction	Boundary and Initial Conditions for Seasonal Climate Prediction Models	Hydroclimatology
	Testing Land Surface Models in General Circulation Models	
Drought and Agriculture Monitoring	Seasonal Precipitation Prediction	Hydroclimatology
	Regional Drought Monitoring	
	Crop Outlook	
Flood Forecast	River Forecast Model Initialization	Hydrometeorology
	Flash Flood Guidance (FFG)	
	NWP Initialization for Precipitation Forecast	
Human Health	Seasonal Heat Stress Outlook	Hydroclimatology
	Near-Term Air Temperature and Heat Stress Forecast	Hydrometeorology
	Disease Vector Seasonal Outlook	Hydroclimatology
	Disease Vector Near-Term Forecast (NWP)	Hydrometeorology
Boreal Carbon	Freeze/Thaw Date	Freeze/Thaw State

Requirement	Hydro-Meteorology	Hydro-Climatology	Carbon Cycle	Baseline Mission		Minimum Mission	
				Soil Moisture	Freeze/Thaw	Soil Moisture	Freeze/Thaw
Resolution	4–15 km	50–100 km	1–10 km	10 km	3 km	10 km	10 km
Refresh Rate	2–3 days	3–4 days	2–3 days(1)	3 days	2 days(1)	3 days	3 days(1)
Accuracy	4–6% **	4–6%**	80–70%*	4%**	80%*	6%**	70%*

(*) % classification accuracy (binary Freeze/Thaw)
(**) % volumetric water content, 1-sigma

(1)North of 45N latitude

Mission Duration Requirement:
3 Years Baseline; 18 Months Minimum

National Aeronautics and
Space Administration

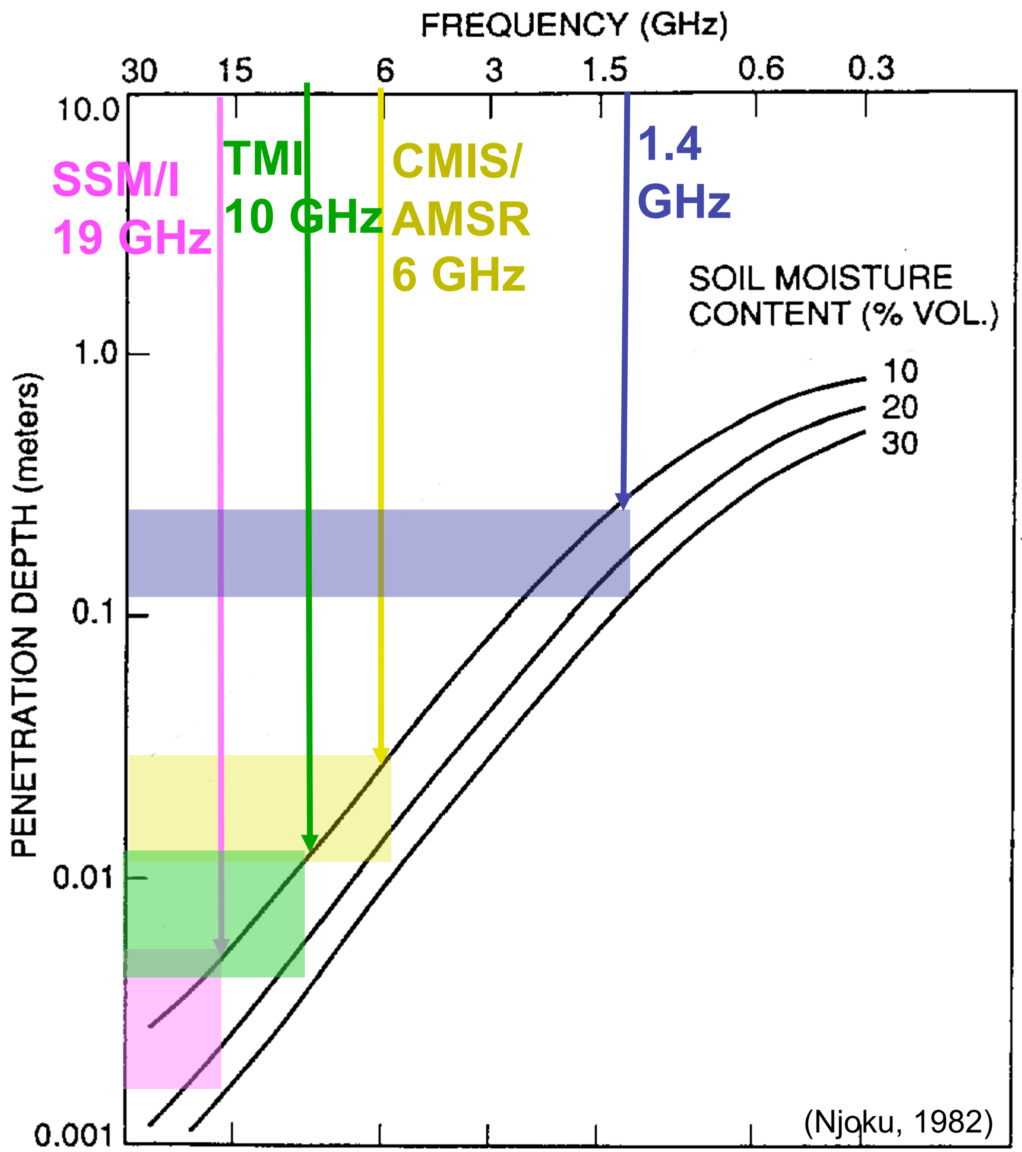
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Sensing Depth Across μ-Wave Frequencies

λ = Wavelength
n''=**Im**{Refractive Index}
Power Attenuates as $e^{-z/d}$

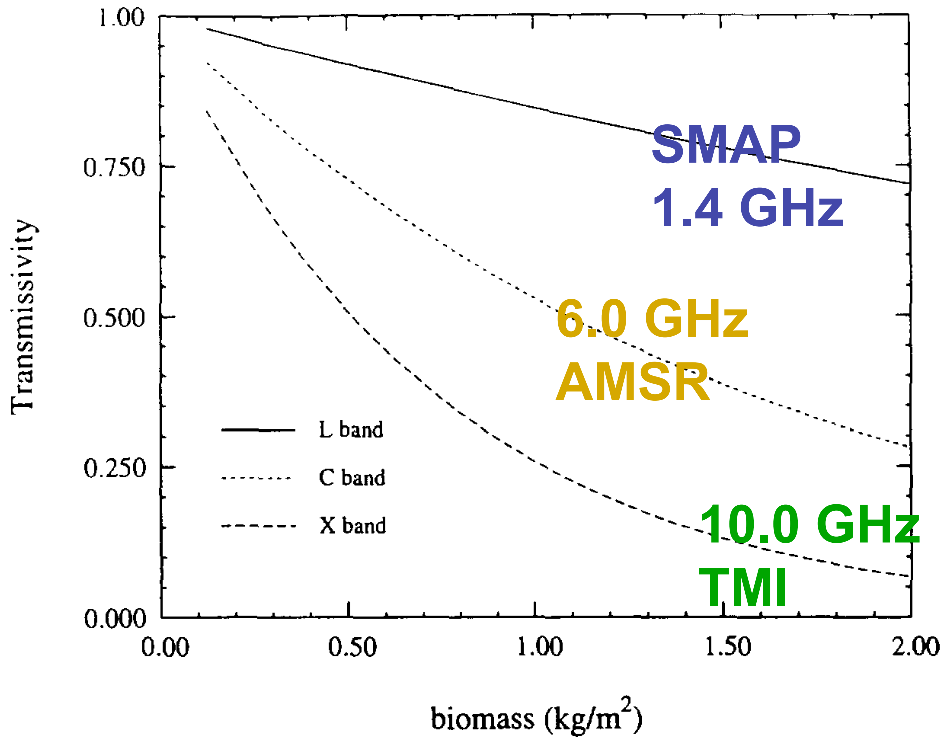
$$d = \frac{\lambda}{4 \cdot \pi \cdot n''}$$

Existing Sensors	SSM/I **19 GHz**	Top <1 mm
	TMI **10 GHz**	Top 1 mm
	AMSR/MIS **6 GHz**	Top 1 cm
Future	SMAP **1.4 GHz**	Top 5cm



Vegetation Opacity at μ-Wave Frequencies

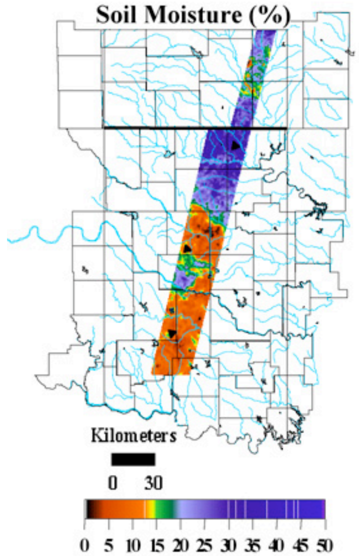
National Aeronautics and
Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

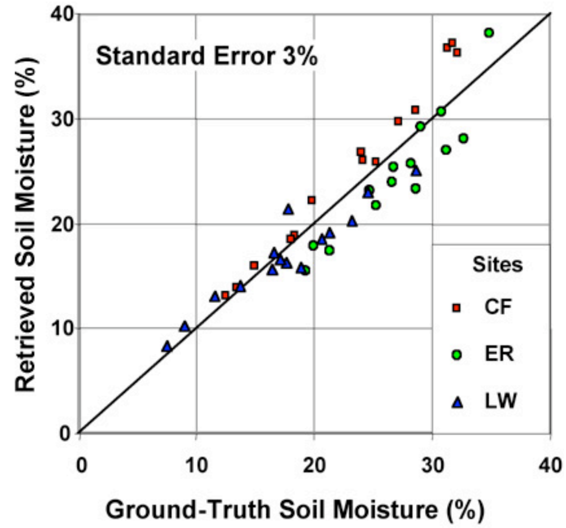


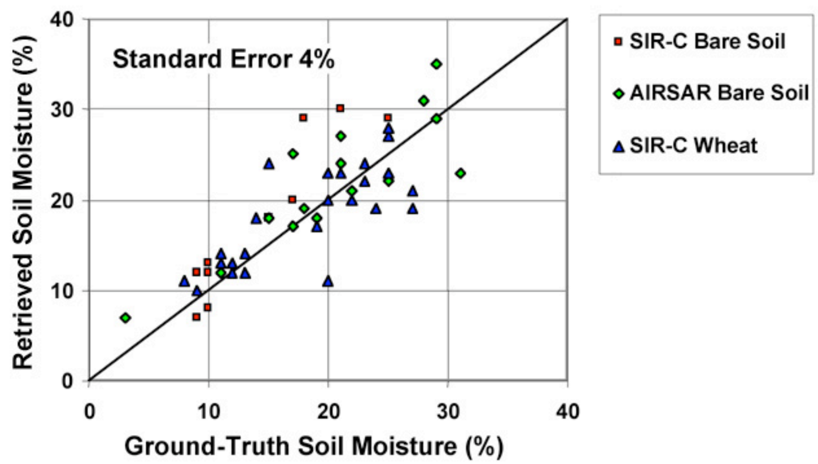
For Example: Signal Loss Over Short Vegetation Cover
100% Lost at 19 GHz (SSM/I)
95% Lost at 10 GHz (TMI)
75% Lost at 6 GHz (MIS/AMSR)
25% Lost at 1.4 GHz (SMAP)

L-band Active/Passive Assessment

- Soil moisture retrieval algorithms are derived from a long heritage of microwave modeling and field experiments
  - MacHydro'90, Monsoon'91, Washita'92, FIFE, HAPEX, SGP'97,'99, SMEX'02-'05
- ***Radiometer*** - High accuracy (less influenced by roughness and vegetation) but coarser spatial resolution (40 km)
- ***Radar*** - High spatial resolution (1-3 km) but more sensitive to surface roughness and vegetation
- **Combined Radar-Radiometer** product provides optimal blend of resolution and accuracy to meet science objectives
- Algorithm approach has been demonstrated in Hydros risk-reduction; OSSE published (Crow et al., 2005); demonstration extended in SMAP Algorithm Testbed







National Aeronautics and Space Administration

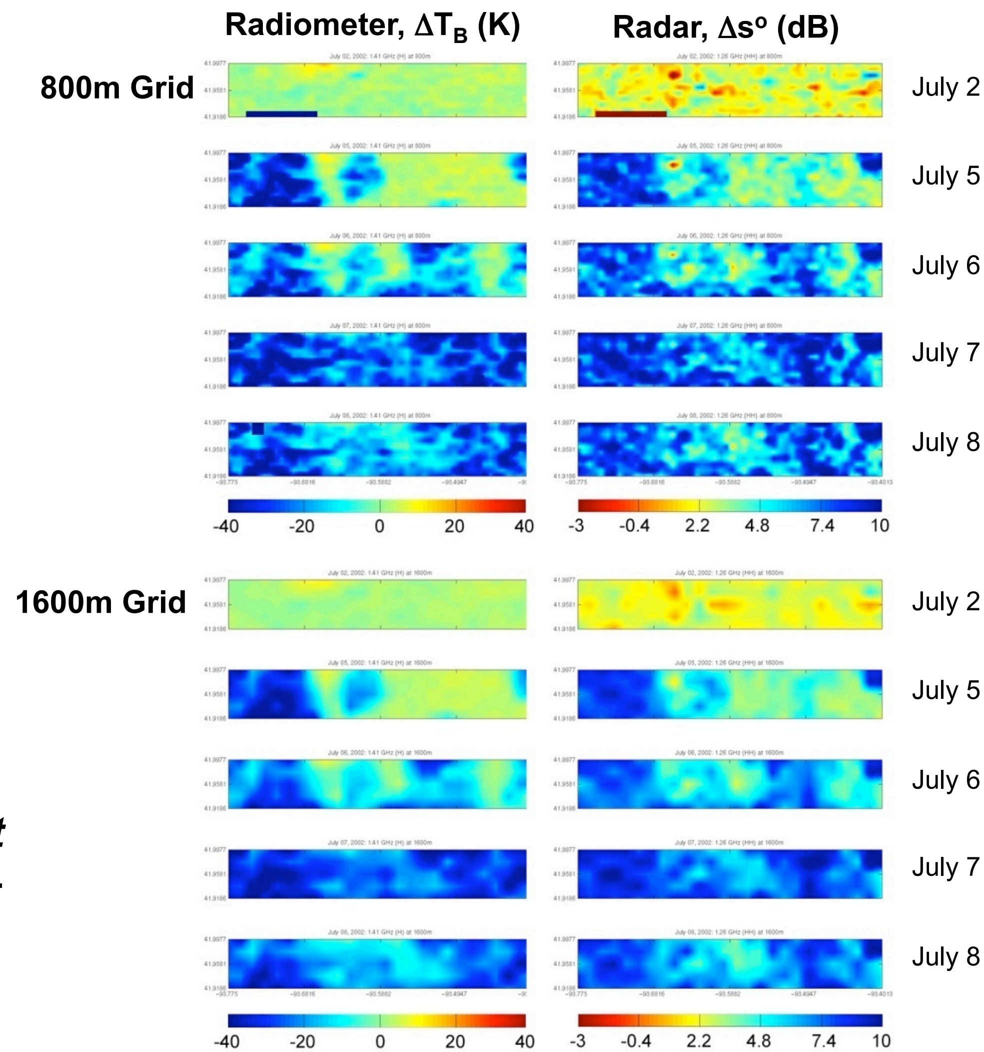
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

SMEX'02 PALS Relative Change Images

Differences from June 25 (dry conditions)

- Difference images show changes in sensor responses (ΔT_B and $\Delta\,\sigma^o$) due primarily to changes in moisture, but with some effects of vegetation growth
- Spatial patterns and temporal changes are consistent between the radar and radiometer
- Artificially degrading spatial resolution by a factor of two by linear averaging of ΔT_B (K) and Δs^o (dB) to 1600 m grid does not change the patterns of variability

⇒ ***Effects of vegetation on radar and radiometer signatures are different, but temporal change patterns are similar – dominated by soil moisture***

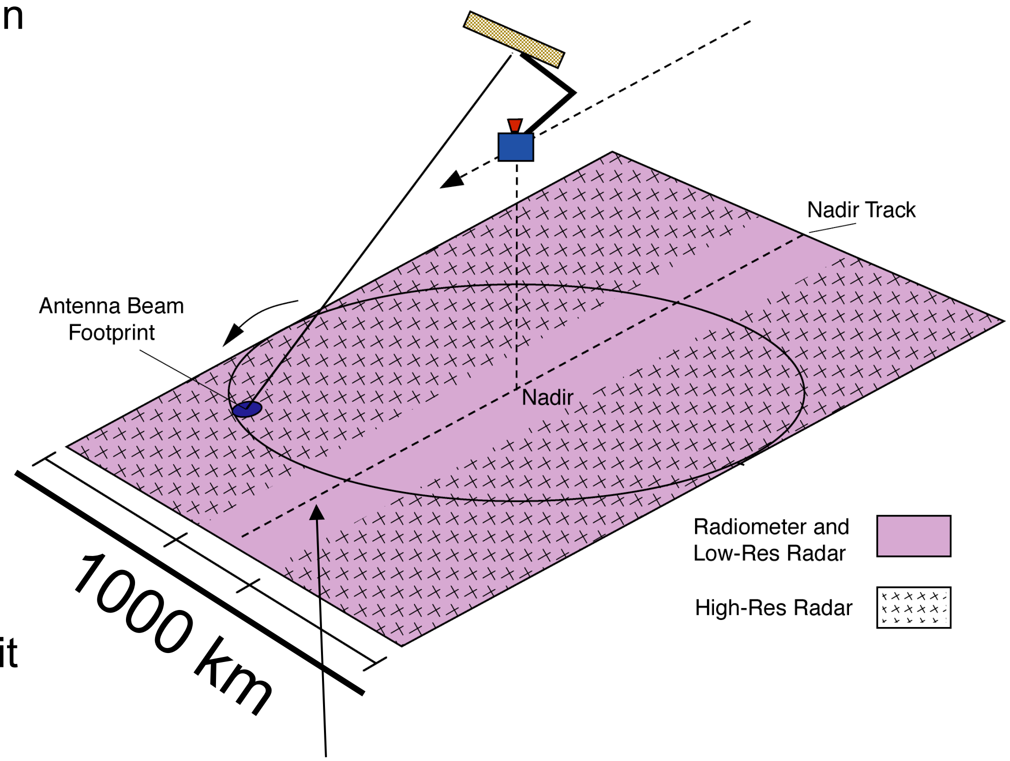


SMAP Measurement Approach

- Instruments:
  - **Radar:** L-band (1.26 GHz)
    - High resolution, moderate accuracy soil moisture
    - Freeze/thaw state detection
    - SAR mode: 3 km resolution
    - Real-aperture mode: 30 x 6 km resolution
  - **Radiometer:** L-band (1.4 GHz)
    - Moderate resolution, high accuracy soil moisture
    - 40 km resolution
  - **Shared Antenna**
    - 6-m diameter deployable mesh antenna
    - Conical scan at 14.6 rpm
    - Constant incidence angle: 40 degrees
      - 1000 km-wide swath
      - Swath and orbit enable 2-3 day revisit

- Orbit:
  - Sun-synchronous, 6 am/pm orbit
  - 670 km altitude

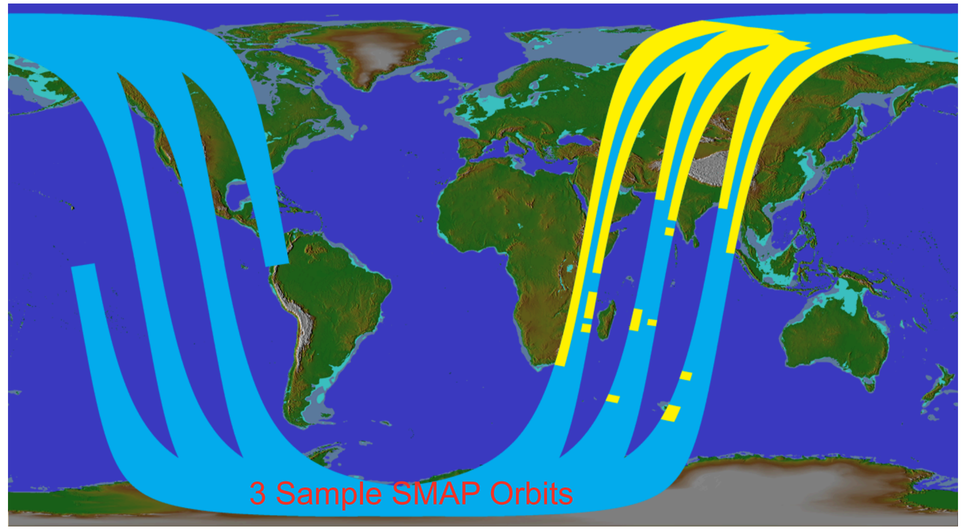
- Mission Operations:
  - 3-year baseline mission



Orbit and Data Collection

Orbit Selection

- Key orbit drivers:
  - 2-3 day revisit time requirements
  - Minimize antenna size, impact to S/C design
- Baseline orbit inclination: sun-synchronous (98 deg) at 6am/6pm.
  - Consistent dawn collection optimal for science, minimizes effect of Faraday rotation.
  - Minimizes impact on S/C design.
- Orbit maintenance and knowledge requirements:
  - Altitude maintained to 1 km over mission
  - Altitude knowledge to 100 m, along/cross-track 1 km



Radiometer and Low-Res Radar   High-Res Radar

Instrument Operations Concept

- Radiometer and low-res radar: Collected continuously 24/7 over the entire globe.
- High-res radar data collected over land during AM portion of orbit. Collection pattern driven by coarse land-map on-board S/C.

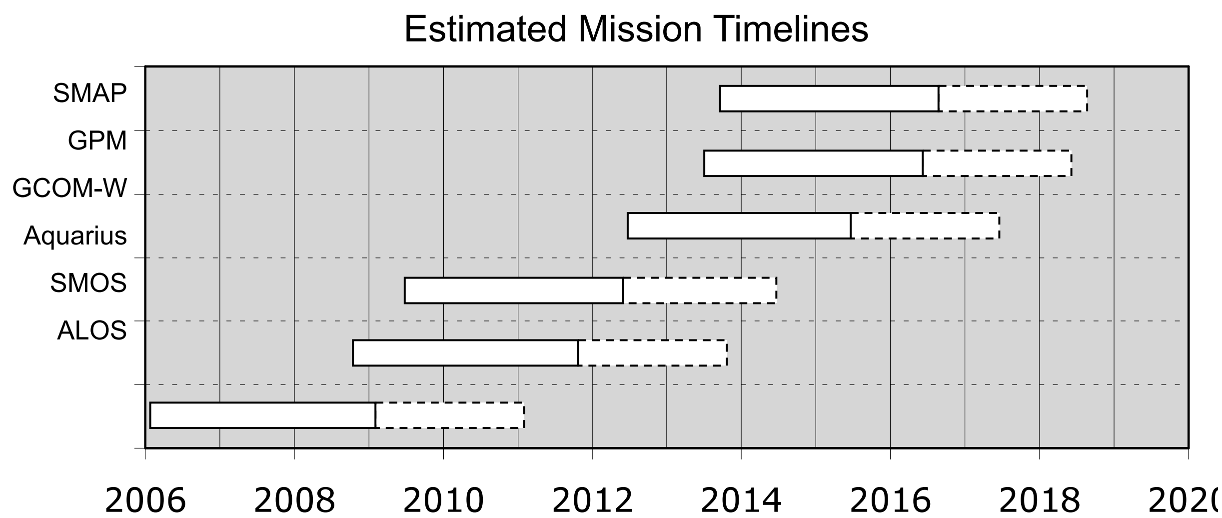
SMAP Science Data Products

Data Product	Description	
L1B_S0_LoRes	Low Resolution Radar σ^o in Time Order	Global Mapping L-Band Radar and Radiometer
L1C_S0_HiRes	High Resolution Radar σ^o, Gridded	
L1B_TB	Radiometer T_B in Time Order	
L1C_TB	Radiometer T_B, Gridded	
L3_F/T_HiRes	Freeze/Thaw State on Earth Grid	High-Resolution and Frequent-Revisit Science Data
L3_SM_HiRes	Radar Soil Moisture on Earth Grid (Internal Product)	
L3_SM_40km	Radiometer Soil Moisture on Earth Grid	
L3_SM_A/P	Radar/Radiometer Soil Moisture on Earth Grid	
L4_F/T	Freeze/Thaw Model Assimilation on Earth Grid	Observations+Model Value Added Product
L4_SM	Soil Moisture Model Assimilation on Earth Grid	

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

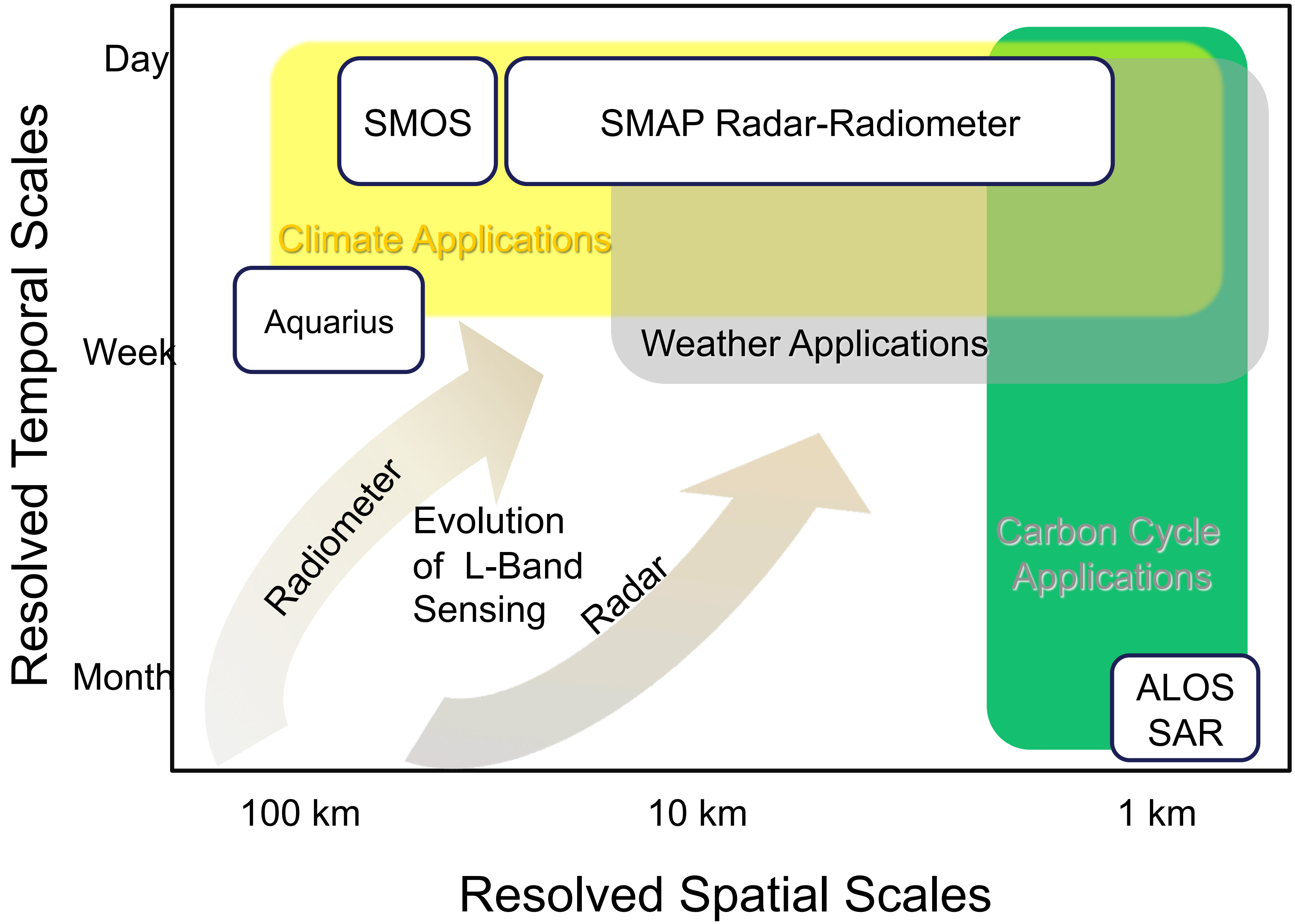
SMAP Synergy With L-Band Missions



SMAP provides continuity for L-band measurements for ALOS, SMOS, and Aquarius: Multiyear data-sets enable new science on climate variability and analogues of climate change

SMAP 1-3 km, 2-3 day global L-band multipolarization mapping data provide potential for multiple new microwave applications - Similar to MODIS value for optical/IR

Evolution of L-Band Remote Sensing



Summary

1. A High Return (Both Science and Application) Earth Science Mission
2. Design Matured With Hydros Heritage
3. Now in Phase A as NASA Directed Mission (Start Phase B in May 2009)
4. Measurement and Algorithms Matured With Many Airborne Experiments
5. Mapping L-Band Radar Mapping Data Has Many More Applications

- **Planned Mission Development Schedule**
  - Phase A start: September 2008
  - SRR/MDR: February 2009
  - PDR: January 2010
  - CDR: December 2010
  - Instrument Delivery April 2012
  - Launch: March 2013